BRL

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EXPERIMENTAL DATA FORMING THE BASIS FOR THE BOMBING TABLES BT-1000-B-1 FOR THE BOMB, A.P., 1000-LB., M52

by

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Abstract

This report records the essential data on which the bombing tables, BT-1000-B-1, are based. A short description of the bomb is given as well as the mechanical constants of the bombs used. The methods used in range bombing and the methods of obtaining essential data are described. Also given are the methods used to determine the ballistic coefficients, as well as the methods used in constructing the bombing tables. Graphs showing the results of range bombing and graphs showing the fitted C : Y relations are included.

I. Purpose of Report

The purpose of this report is to record the essential details of the experimental work, the computing methods and the experimental data upon which the bombing tables, BT-1000-B-1, for the Bomb, A.P., 1000-lb., M52 are based.

II. Description of Bombs

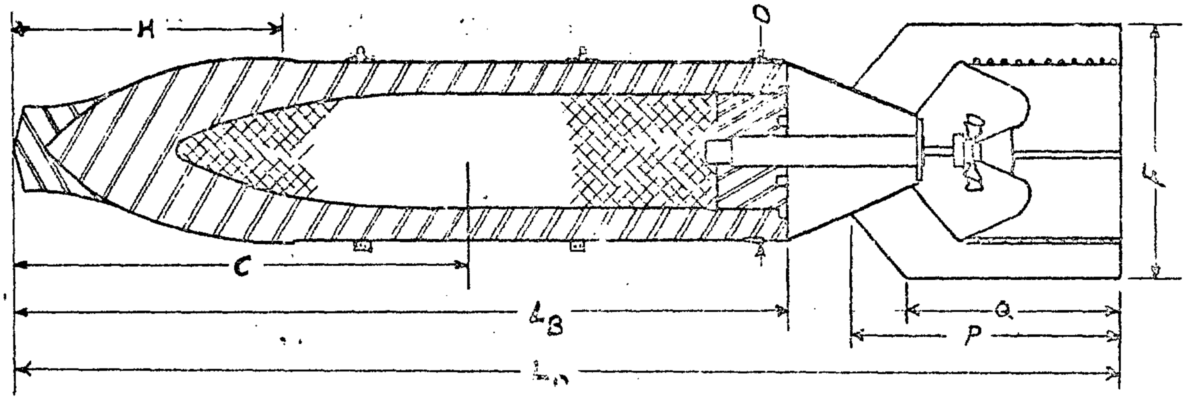
The Bombs, A.P., 1000-lb., M52 used in range bombing for the bombing tables, BT-1000-B-1, were made in accordance with Picatinny Arsenal Drawing Number 26454, dated February 6, 1941. The present Ordnance Drawing Number is 82-0-58, dated September 15, 1941.

This armor-piercing bomb was made by converting the 12" Deck Piercing Shell, M1898 (Ordnance Drawing Number 75-12-4D). The shells have been converted into bombs by adding lugs to the body and by adding a fin assembly to the tail of the shell. The base plug has been altered so that the fuze hole is smaller and a smaller adapter is used. The rotating bands have been machined so that they have the same diameter as the bomb body. One half of the bombs dropped in this range bombing program were modified and half were unmodified. The unmodified bombs were equipped with

PHYSICAL CHARACTERISTICS

BOMB, A.P., 1000-LB., M52

DRG. NO. 82-0-58 REV. 9-15-41



PRINCIPAL DIMENSIONS

DIMENSION	INCHES	CALIBERS	REMARKS
D	12.25	1.00	[illegible]
B	11.25	.91	[illegible]
F	16.6	1.36	[illegible]
L_o	70.88	5.79	[illegible]
L_B	49.53	4.04	[illegible]
H	16.1	1.31	AS [illegible] ON DRAWING
P	17.6	1.44	[illegible]
Q	14.4	1.18	[illegible]
C	28.3 σ=0.153	2.31	[illegible]
C		[illegible]	

COMPONENTS AND WEIGHTS

COMPONENTS		WEIGHT	REMARKS
BODY ASSEMBLY	BODY	983.	INCLUDING [illegible] LESS
	ADAPTER-BOOSTER	2.16	LESS CLOSING PLUG
	ADAPTER	6.	AS GIVEN ON DRAWING
	BURSTING CHARGE	58.35	AS GIVEN ON DRAWING
	COMPLETE AS LOADED	1049.5	AS GIVEN ON DRAWING
	COMPLETE AS LOADED		[illegible]
FIN ASSEMBLY		21.	AS GIVEN ON DRAWING
FUZE, NOSE,			
FUZE, TAIL, M102 OR M102A		3.20	AS GIVEN ON DRAWING
FIN COUPLING AND LOCK NUT		3.70	AS GIVEN ON DRAWING
COMPLETE AS DROPPED		1077.	AS GIVEN ON DRAWING
COMPLETE AS DROPPED		[illegible] σ=[illegible]	[illegible]

EXPECTED MAXIMUM VARIATION IN WEIGHT AS [illegible]

RATIO, WEIGHT OF BURSTING CHARGE: WEIGHT AS DROPPED =0.05[illegible]

EXPERIMENTAL DESIGNATION:	STANDARDIZED BY:

PREPARED IN BAL. RES. LAB. A.P.G.

lug-bands and were filled with Explosive D. The modified bombs had their lugs screwed on the body and were filled with cast TNT. The unmodified bombs are numbered 12, 14, 16, 18, 20, 22, 24, 26, and 28. The modified bombs are numbered 11, 13, 15, 17, 19, 21, 23, 25 and 27. The modified bombs carried an experimental designation of T1.

The bomb is assembled with Fuze, Bomb, Tail, M102 (modified). This is a vane type fuze with a 0.04 to 0.06 second delay. The bomb was equipped with steel box-type fins. The percentage of bursting-charge to actual weight as dropped is 5.4 per cent. The range bombing program was authorized in correspondence.00 471.62/222.

III Preparation of Bombs

The bombs were fully loaded when received at the Proving Ground, so that it was only necessary to assemble fins and fuzes to them.

IV Mechanical Constants of Bombs

The mechanical constants of each bomb were determined before it was loaded into the airplane.[1] The detailed results of these measurements are given in Appendix A. A summary of the results for the Bomb, A.P., 1000-lb., M52 is given in the table below:

	m Weight Complete as Dropped lb.	$\bar{x}$ Distance of Center of Gravity from Nose in.	I_T Moment of Inertia about Transverse Axis through Center of Gravity lb.ft.^{2}
Mean	1080.3	28.32	1566
Standard Deviation	2.30	0.15	7
Maximum	1086.0	28.82	1584
Minimum	1076.5	28.13	1552
Number of Bombs	17	17	17

[1] No moments of inertia about the longitudinal axis were obtained for these bombs.

These statistics refer to all bombs for which a ballistic coefficient with respect to any element was obtained. The actual variations in weight of these bombs do not affect their flight characteristics sufficiently to cause a variation in ballistic coefficient large enough to be detected by the methods for estimating the ballistic coefficient which were used in the reduction of field data. The variation in center of gravity position and moments of inertia would, if sufficiently in excess of that for the present bombs, affect the yaw of the bombs and thereby the dispersion in the elements range, time of flight and trail.

The positions of the centers of gravity of the bombs summarized above were measured with fins and fuzes.

V. Description of the Range Bombing

The bombs in this range bombing program were dropped from the B-18A, and the B-23 airplanes at a target anchored in Bush River in such a position that the release points were in the fields of view of the Vertical and Oblique Cameras Obscura. The direction of the approach to the release points on all runs was from southeast to northwest within 15°

On all approaches on which bombs were dropped horizontal flight was maintained as nearly as possible. In all cases except May 3, 1941, the piloting was done by means of the automatic flight control equipment. On this date the equipment did not work and the piloting was done manually.

In these airplanes the bomb racks are so arranged that the longitudinal axis of the bomb is nearly parallel to the thrust line of the airplane. Hence the initial yaw of the bomb in the vertical plane is nearly equal to the angle of attack of the airplane.

On all approaches with the B-18A airplane, the bombs were carried in the rear bank of the bomb racks. The center line of this rack is 12.8 feet to the rear of the point formed by the junction of the front edge of the wing with the fuselage of the airplane, this junction being the point on the airplane plotted in the cameras obscura. The corresponding distance in the B-23 is 12.1 feet.[1]

All bombs were dropped according to the current standard practice of the Air Corps, using the current standard bomb sight and a target in Bush River as an aiming point. The results of this range bombing are shown in Appendix B. For the

[1] The effect of bomb bay release position on the estimated values of the ballistic coefficients is discussed in Ballistic Research Laboratory Report No. 136: "First Progress Report: On the Method of Reduction of Observations on the Elements of Bomb Trajectories."

purpose of this report, the displacement of the center of impact with respect to the target is of no special significance. The dispersion about the center of impact and other data summarized in Appendix B are, however, of considerable interest.

The bombs dropped were divided into groups and the endeavor was made to have the altitude and air speed within the group approximate as nearly as possible to certain specified values. These values were described as the standard altitude and the standard air speed.[1]

The number of bombs in each group and the standard altitude and standard air speed for each group are given in Appendix D. The reasons for the selection of these standard altitudes and air speeds are given in Sections VI and IX of this report.

The range bombing was conducted by the following:

Pilots:

Capt. S. C. Smink, A.C.
First Lt. R. Billings, A.C.
First Lt. A.C Perry, A.C.
First Lt. C.A. Reissaus, A.C.

Bombardiers:

Capt. M. F. Summerfelt, A.C.
Capt. S. C. Smink, A.C.

Proof Officers:

Capt. J. G. Shinkle, O.D.
Mr. C. Brown, O.D.

VI. Ground Observations

The primary ground observational equipment employed was the Camera Obscura Installation.[2] The position of the aircraft in space and its components of velocity were fundamental data obtained by reduction of observations made with this equipment.

[1] Compare the usage of these terms for statistical purposes in Sections VIII and IX of this report.

[2] A basic description of the Camera Obscura Installation is given in the "First, Second and Third Progress Reports on Bomb Trajectory Study by the Camera Obscura Method" by Frank Short, F. V. Ludden and S. P. Willan. The equipment has been extensively modified and improved during 1938 and the current equipment and its accuracy are described in Ballistic Research Laboratory Report No. 144: "First Progress Report: On the Accuracy of the Camera Obscura Installation for Obtaining the Initial Data of Bomb Ballistics."

The field data for determinations of times of flight were secured by the chronograph installation housed in the Vertical Camera Obscura. The instants of release and impact were recorded by this chronograph-hydrophone system which has been in use in the present form since 1937.[1] In addition the field data for determinations of the times of flight of 8 bombs were obtained by the Western Electric Camera Clock. The clock in the camera is started by the same radio release signal that is recorded by the chronograph-hydrophone system cited above. The camera photographs the impact of the bomb on Bush River and the clock face within the camera at the same instant. The rate of the camera at this time was approximately 200 frames per second.

The coordinates of the impacts referred to the camera coordinate system were obtained by the ground observers by means of azimuth instruments on three towers along the shore of Bush River and were furnished to the Bombing Unit of the Ballistic Research Laboratory. The ground observers also provided the dispersion data with reference to the target and the reduced meteorological data for securing corrections to the elements tabulated in the bombardier's approximate bombing tables. The latter results are graphically summarized in Appendix B, "Primary Results of Range Bombing".

The field data necessary for the reduction of the effects of non-standard meteorological conditions were obtained from two sources. The data secured by the camera observers were the coordinates on the camera plotting boards of smoke puffs at regular time intervals for a series of altitudes, to be used in obtaining ballistic winds; the velocity and the direction of the wind at the earth's surface; and the temperature, the relative humidity and the barometric pressure of the air at the earth's surface. The data secured by the Range Observation Section observers were the spatial positions of a balloon at regular time intervals, and the velocity and direction of the wind at the earth's surface. The temperature and barometric pressure at a series of altitudes were obtained from the bombing flight records of the bombardier. These data were partially reduced by the Range Observation Section and were furnished to the Bombing Unit in the form of tables of:

[1] The calibration of this system and the measurement of the systematic errors to which it is subject were carried out in 1938 and are described in Ballistic Research Laboratory Report No. 130: "On the Measurement of the Time of Flight of Bombs". The absolute accuracy and internal precision of the method in actual practice has been determined recently and the results are given in Ballistic Research Laboratory Report No. 211: "Comparison of Measures of the Time of Flight of Bombs by the Camera Obscura Chronograph and the Western Electric Clock".

(1) The actual wind components at a series of altitudes, and
(2) The density of the air at a series of altitudes relative to standard ordnance air density structure.

The actual wind components were taken along a fixed line of known azimuth in the bombing lane, with the sign positive when taken along the direction of flight and positive when taken to the right. The actual wind components and the densities were obtained as near to the time the bombs were dropped as was practicable.

Field data on range bombing with the Bomb, A.P. 1000-lb., M52 for the bombing tables, BT-1000-B-1, were obtained from the program carried out between April 28, 1941 and June 6, 1941. This included range bombing at 2,000, 10,000 and 25,000 foot altitudes. The advance of ballistic theory and increased accuracy of measurement during 1938 and 1939 showed that better results can be obtained from groupings at the maximum obtainable altitude of release, a central altitude and a low altitude.

Field data for both range and time of flight were obtained and trail determinations were made wherever possible. A total of 17 ranges,[1] 21 times of flight and 19 trails was obtained.

VII. Reduction of Field Data

The data secured by the ground observers at the cameras were utilized to obtain the position and velocity of the airplane at the instant of release. The data secured by the ground observers at the azimuth instruments were utilized to obtain the positions of impact of the bombs. The time intervals obtained from the chronograph strip were employed to determine the uncorrected interval between release and impact. The time intervals from the Western Electric Camera film were likewise utilized. These data were then corrected for instrumental errors.[2]

[1] On May 27, 1941, Run Number 1, Bomb Number 23, the short range and less than vacuum times (microphone and Western Electric) indicate the bomb left the plane approximately 1/3 second before the release signal was received. Therefore the values were not included in the group mean.

[2] The character of these instrumental errors is discussed in Ballistic Research Laboratory Reports No. 144, 130 and 211, previously cited.

VIII. Determination of Ballistic Coefficient

The reduction of field data furnished values of range and time of flight corresponding to a certain set of known values of altitude and air speed, but containing the effects of departures from standard ballistic table conditions.[1] The method of reduction of field data in order to obtain ballistic coefficients with respect to range, time of flight and trail is discussed very briefly in Ballistic Research Laboratory Report No. 191.[2] The computation of the ballistic coefficients is carried out by means of a Bomb Ballistic Reduction Table which was prepared in the Ballistic Research Laboratory.[3]

In accordance with the principles remarked above the ballistic coefficients corresponding to the ranges, times of flight and trails were then deduced for each individual bomb. From these coefficients the ranges, times of flight and trails were then computed for the standard altitude and standard air speed of the group to which the bomb belonged. These are called the "standard ranges", the "standard times of flight" and the "standard trails", or in general, the "standard elements" and are given in Appendix C together with the corresponding ballistic coefficients. This appendix also lists the program, the group, the serial number stamped on the bomb, the date of release and the run number, the last two providing for comparison with Appendices A and B.

The standard elements and the ballistic coefficients corresponding thereto contain the effects of certain unknown instrumental inaccuracies and of certain departures from standard bombing table conditions which it was not feasible to remove in advance. However, the effects of these sources of dispersion were partially removed by the process used for construction of the bombing tables.

[1] Standard ballistic table conditions and standard bombing table conditions are discussed and compared in Ballistic Research Laboratory Report No. 145: "On the Theory of Motion of the Bomb".

[2] The method of reduction of field data in order to obtain ballistic coefficients with respect to range, time of flight and trail has undergone considerable evolution. The reports from which the present methods were developed include: Ballistic Research Laboratory File E-IV-3, "Explanations and Comparisons of the Camera Obscura Methods of Computation"; "Computation of Firing Tables for the U. S. Army"; and Ballistic Research Laboratory Report No. 136, previously cited.

[3] A discussion of the ballistic coefficients corresponding to range, time of flight and trail is given in Ballistic Research Laboratory Report No. 143: "Errors in Trail Resulting from Ignoring Either the Measured Range or the Measured Time of Flight".

IX. Construction of Tables

The experimental data from which the ballistic coefficients with respect to range, time of flight and trail were determined fell into 3 altitude groups. The groups were for standard altitudes of 2,000, 10,000 and 25,000 feet. The dependence of the ballistic coefficients upon altitude of release was determined from these 3 groups.

The mean standard elements for a standard true air speed and altitude were determined for each altitude group. The mean standard element is the arithmetic mean of the individual standard elements.[1] The individual standard elements used in computing the mean standard elements had been reduced to the group standard altitude and true air speed. The use of the mean standard elements reduces the influence of the accidental errors in the individual standard elements upon the elements tabulated in the bombing table. The ballistic coefficients corresponding to these mean standard elements were then deduced. The forms of the functional dependence upon altitude of the three ballistic coefficients have been derived theoretically and verified empirically.[2] The lift is the cause mainly responsible for the character of the variation of the ballistic coefficients with altitude. The lift is due to the yaw arising from the initial angular velocity of the tangent to the trajectory. The effects of lift are allowed to remain in the ballistic coefficients corresponding to the mean standard elements. The functional relations referred to are:

[1] When time of flight was obtained by both the chronograph-hydrophone system and the Western Electric Camera Clock for one bomb, the average resulting is given a weight of 2 in the determination of the airthmetic mean. The average trail resulting from one measure of range and an average of the two times of flight was given a weight of 1.5.

[2] The derivation of the form of these relations between the ballistic coefficients and the altitudes of release is discussed in Ballistic Research Laboratory Report No. 145, previously cited.

$$C_{X_y} = \frac{C_{X_\infty}}{1+ \frac{k_X C_{X_\infty}}{\sqrt{Y}}}$$

$$C_{T_y} = \frac{C_{T_\infty}}{1+ \frac{k_T C_{T_\infty}}{\sqrt{Y}}}$$

$$C_{\lambda_y} = \frac{C_{\lambda_\infty}}{1+ \frac{k_\lambda C_{\lambda_\infty}}{\sqrt{Y}}}$$

These curves each contain two empirical qualtities k and C_∞.

The subscript ∞ refers to the mean effective ballistic coefficient for infinite altitude, and k is a parameter determining the shape of the curve.

A new procedure for estimating the values of C_{X_∞}, C_{T_∞}, C_{λ_∞}, k_X, k_T and k_λ was in use when these bombing tables were computed. The first modification consisted in changing the method of weighting the points. The earlier procedure assigned weights proportional to the product of the number of bombs in the group and a factor dependent upon a priori considerations of the probable accuracy of the determination. No account was taken of the fact that the probable error of bombing is an increasing function of the altitude of release. In consequence, unduly great weight was attached to the groups of bombs at the high altitude. The new procedure for range and trail used weights proportional to the product of the number of bombs in the group, a factor dependent upon a priori considerations of the probable accuracy of the determination and the reciprocal of altitude of release. The new procedure for the time of flight used weights proportional to the product of the number of bombs in the group, a factor dependent upon a priori considerations of the probable accuracy of the determination, the reciprocal of the altitude and the standard true air speed. The second modification consisted in a change of the functions to be minimized. The function minimized in the earlier procedure was the sum of the weighted squares of the residuals of the reciprocal ballistic coefficients. The function minimized in the new procedure was the sum of the weighted squares of the residual differences between the mean standard elements and those elements which would result from the use of the bombing tables.[1] This modification has resulted in much smaller probable ballistic errors for bombing tables.[2] A considerable improvement in the accuracy of the bombing tables, has resulted therefrom. The improvement is shown by the magnitude, as compared with earlier bombing tables, of the differences between the observed mean standard ranges, times of flight and trails, and those elements which would result from employment of these tables.

The values C_{X_∞}, C_{T_∞}, C_{λ_∞}, k_X and k_λ were deduced by the new procedure described above; k_T was shown to be without significance in the present instance. The values were:

$$C_{X_\infty} = 5.155 \; ; \; C_{T_\infty} = 4.282 \; ; \; C_{\lambda_\infty} = 3.722$$

$$k_X = -1.832 \; ; \; k_T = 0 \; ; \; k_\lambda = -7.848$$

The observed and fitted ballistic coefficients are compared in Tables 1, 2 and 3 of Appendix D. The relations between the fitted ballistic coefficients and the altitudes of release are shown in Plots I, II and III of Appendix D. The fitting provides for obtaining the ballistic coefficient for any altitude of release. The actual points on the plots in Appendix D are shown by dots and their probable errors by horizontal strokes placed on the sides of the dots. The computed C : Y relations are shown by heavy lines. The dotted lines furnish the probable error of forecast bands. The band is determined by addition and subtraction of the probable error of the computed C : Y relation from the curve.

The construction of the Table of DS followed general instructions given in file OO 063.2/4524 (Confidential). The trail angles, times of flight and dropping angles were obtained by interpolation with the fitted C : Y relations in the Bomb Ballistic Auxiliary Tables, computed in the Ballistic Research Laboratory. These tables give trail angles, times of flight and dropping angles as functions of the altitude of release, Y; the calibrated indicated air speed, V, or true ground speed, V_g; and the reciprocal ballistic coefficient, $\frac{1}{C}$. The intervals

[1] The new procedure is described more completely in Ballistic Research Laboratory Report No. 136, previously cited.

[2] The ballistic error is a term originally used by British ballisticians to denote the difference between the bombing table range and the mean standard range for the same conditions. The ballistic error is denoted by $X-X_f$ in this report.

of the arguments used in the Bomb Ballistic Auxiliary Tables are the same as those used in the present series of abridged bombing tables. The small differences between the observed mean standard ranges, times of flight and trails, and those elements which would result from employment of these tables are shown in the columns $X-X_f$, $T-T_f$ and $\lambda-\lambda_f$ given in Tables 1, 2 and 3 of Appendix D. These differences are compared with the probable errors of the observed mean standard elements in Plots IV, V and VI of Appendix D. The importance of employment of the fitted C_{X_y} : Y, C_{T_y} : Y and C_{λ_y} : Y curves is shown by the small magnitude of these differences.

The range of arguments included in these bombing tables, BT-1000-B-1, is indicated in the table below:

Element	Speed mi./hr.		Altitude ft.	
	Minimum	Maximum	Minimum	Maximum
Trail Angle (Calibrated Indicated Air Speed)	100	250	1800	35000
DS (Calibrated Indicated Air Speed)	160		1200	36000
Time of Flight (Calibrated Indicated Air Speed)	160		1000	35000
Dropping Angle (Ground Speed)	100	250	100	10000

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Appendix A

Mechanical Constants of Bombs

Appendix A

Mechanical Constants of Bombs[1]

Program Group Serial Number	Date of Release Run Number	m Weight Complete as Dropped lb.	$\bar{x}$ Distance of Center of Gravity from Nose in.	I_T Moment of Inertia about Transverse Axis through Center of Gravity $lb.ft.^2$
-11	4/28/41-1	1080.5	28.35	1566
-12	2	1082.5	28.21	1579
-15	4/29/41-1	1080.0	28.31	1565
-14	2	1080.0	28.27	1561
-13	3	1077.5	28.45	1568
-16	5/3/41--1	1079.5	28.22	1562
-17	2	1079.5	28.82	1570
-18	1	1086.0	28.31	1571
-19	2	1078.5	28.32	1559
-20	5/26/41-1	1076.5	28.13	1552
-21	2	1081.0	28.44	1572
-22	3	1077.5	28.32	1572
-23	5/27/41-1	1080.5	28.21	1564
-24	6/3/41--1	1084.0	28.27	1558
-25	1	1079.5	28.17	1584
-26	2	1082.0	28.28	1566
-27	6/6/41--1	1080.0	28.44	1565

[1] The moments of inertia about the longitudinal axis were not obtained for these bombs because there is no nose fuze hole for the adapter. Interference of the fins plus the fact of the bombs being H.E. loaded made suspension from the tail impractical.

Appendix B

Primary Results of Range Bombing

RESULTS OF RANGE BOMBING NO. 148

APRIL 28, 1941 1000 LB A.P. BOMB T1 AIRPLANE B-23

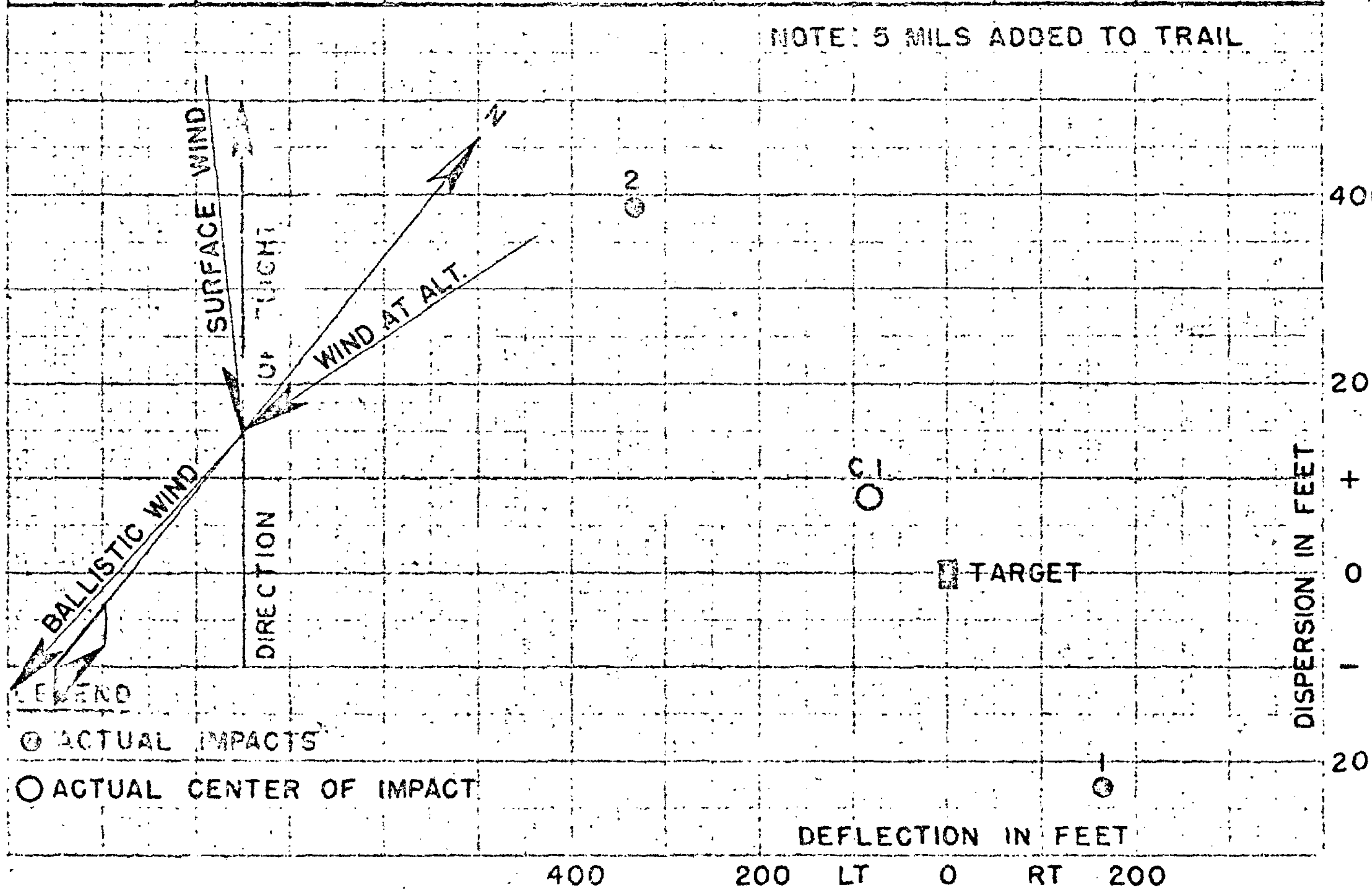
PILOT: W.O. S.C. SMINK BOMBARDIER: CAPT. M.F. SUMMERFELT

SKY: SCTTRD CLOUDS AIR: HAZY-SMOOTH TRAIL AND D.S. BASED ON BT-2000 – B-1

BOMB NO.	TIME OF REL.	ALTITUDE AIR OBS FT.	ALTITUDE GR'ND OBS FT.	AIR SPEED CAL IND M/HR	AIR SPEED TRUE AIR OBS. M/HR	AIR SPEED TRUE GR'ND OBS. M/HR	GR'ND SPEED GR'ND OBS. M/HR	CLIMB OR GLIDE GR'ND OBS. FT/MIN	HOR. RANGE FT.	RANGE OVER FT.	RANGE SHORT FT.	DEFLECTION RIGHT FT.	DEFLECTION LEFT FT.
1	9:37	25465	25277	146	217.6	212.0	196.8	-24.6	10945		228	165	
2	9:48	25465	25224	146	217.4	212.3	198.0	-85.2	11201	387			333
3													
4													
5													
6													
CENTER OF IMPACT										80			84
MEAN DEVIATION										308		249	

		R.O.S.	R.O.S.	CAMERA
TIME		9:27		9:56
WIND VELOCITY M.P.H.	SURFACE	15.0		12.0
	AT ALTITUDE	24.8		26.5
	BALLISTIC RANGE WIND	-22.4		-20.4
	BALLISTIC CROSS WIND	-20.1		-19.8
DENSITY	AT SURFACE	1.003		1.006
	BALLISTIC (SURFACE)	1.012		1.013
	BALLISTIC (AIR OBS.)	1.021		

NOTE: 5 MILS ADDED TO TRAIL



RESULTS OF RANGE BOMBING NO. 149

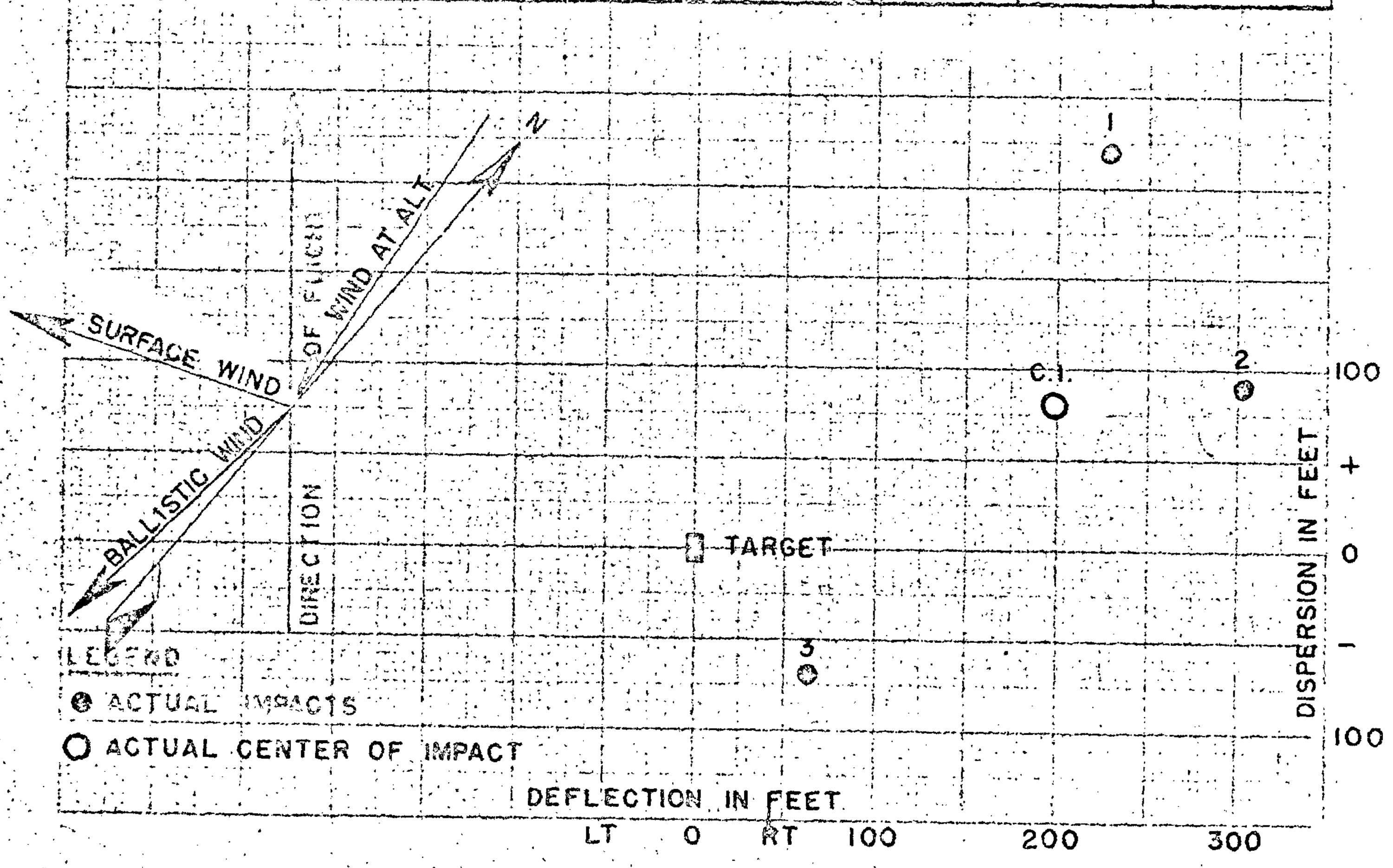
APRIL 29, 1941 — 1000 LB A. P. BOMB T1 — AIRPLANE B-23

PILOT: LT. R. BILLINGS — BOMBARDIER: CAPT. M.F. SUMMERFELT

SKY: HAZY — AIR: SMOOTH — TRAIL AND D.S. BASED ON BT-2000 — B-1

BOMB NO.	TIME OF REL.	ALTITUDE AIR OBS FT.	ALTITUDE GR'ND OBS FT.	AIR SPEED CAL IND M/HR	AIR SPEED TRUE AIR OBS. M/HR	AIR SPEED TRUE GR'ND OBS. M/HR	GR'ND SPEED GR'ND OBS. M/HR	CLIMB OR GLIDE GR'ND OBS. FT/MIN	HOR. RANGE FT.	DEVIATIONS FROM TARGET RANGE OVER FT.	RANGE SHORT FT.	DEFLECTION RIGHT FT.	DEFLECTION LEFT FT.
1	10:03	10500	10317	155	182.4	173.9	168.6	+77.5	6148	219		228	
2	10:15	10500	10223	170	199.8	190.1	184.0	-131.3	6673	90		303	
3	10:29	10500	10251	170	199.9	181.8	176.6	+25.8	6440		69	63	
4													
5													
6													
CENTER OF IMPACT										80		198	
MEAN DEVIATION										99		90	

		R.O.S.	R.O.S.	CAMERA
TIME		9:20	10:40	10:15
WIND VELOCITY M.P.H.	SURFACE	5.0	7.0	3.5
	AT ALTITUDE	13.3	13.7	9.5
	BALLISTIC RANGE WIND	-9.5		-9.9
	BALLISTIC CROSS WIND	-9.8		-9.9
DENSITY	AT SURFACE	1.011	1.000	1.000
	BALLISTIC (SURFACE)	1.014	1.007	1.007
	BALLISTIC (AIR OBS.)	1.026		



RESULTS OF RANGE BOMBING NO. 151

MAY 3, 1941 — 1000 LB A.P. T1 BOMB — AIRPLANE B-23

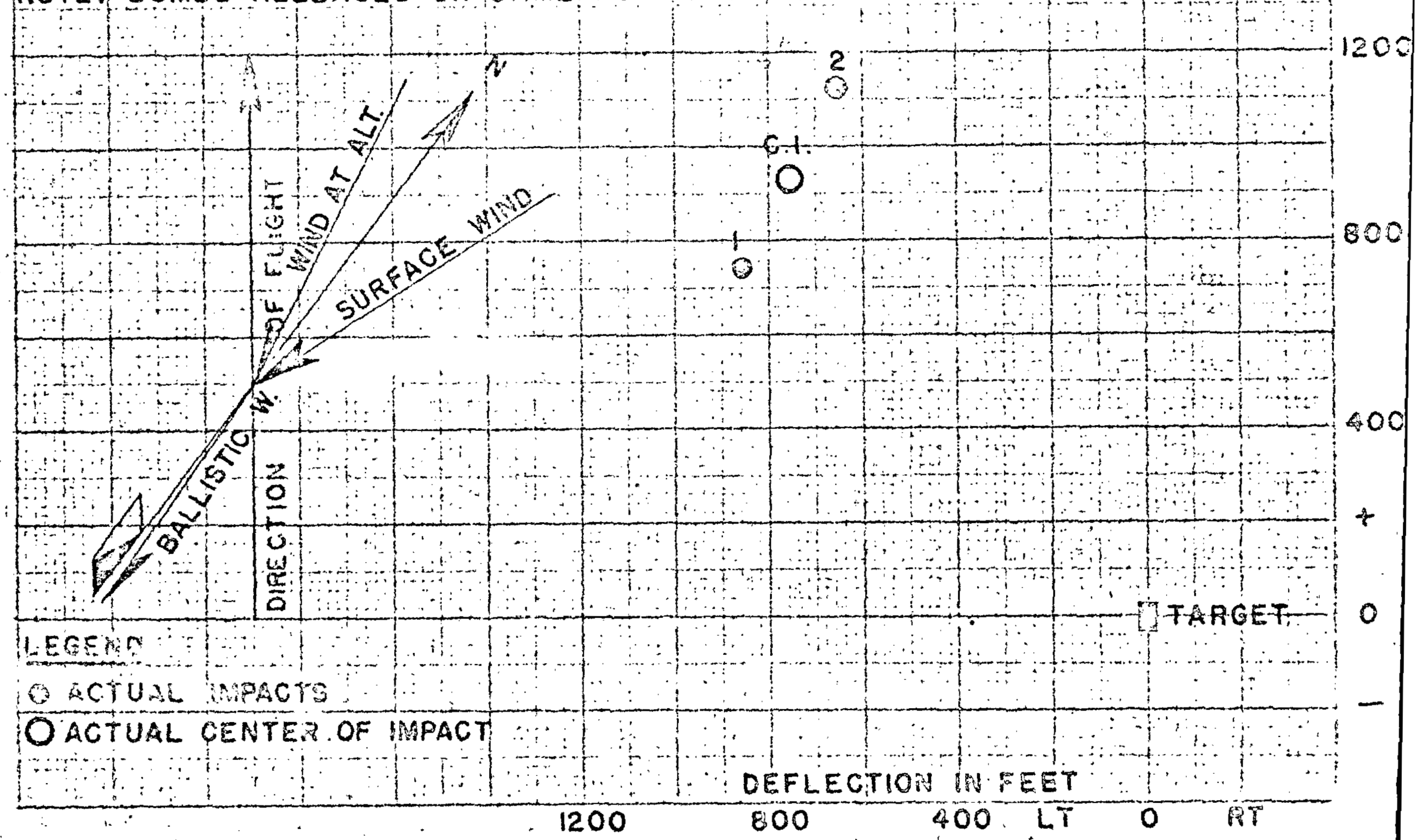
PILOT: LT. R. BILLINGS — BOMBARDIER: W.O. S.C. SMINK

SKY: CLEAR — AIR: SMOOTH — TRAIL AND D.S. BASED ON BT-2000-B-1

BOMB NO.	TIME OF REL.	ALTITUDE AIR OBS FT.	ALTITUDE GR'ND OBS FT.	AIR SPEED CAL IND M/HR	AIR SPEED TRUE AIR OBS. M/HR	AIR SPEED TRUE GR'ND OBS. M/HR	GR'ND SPEED GR'ND OBS. M/HR	CLIMB OR GLIDE GR'ND OBS. FT/MIN	HOR. RANGE FT.	RANGE OVER FT.	RANGE SHORT FT.	DEFLECTION RIGHT FT.	DEFLECTION LEFT FT.
1	10:30	25150	24991	145	215.2	213.5	156.3	+75.4	8712	741			858
2	10:30	25150	25000	145	215.2	213.4	156.2	+120.0	8725	1122			654
3													
4													
5													
6													
								CENTER OF IMPACT		932			756
								MEAN DEVIATION		191		102	

			R.O.S.	R.O.S.	CAMERA
	TIME		10:26		10:38
	WIND VELOCITY M.P.H.	SURFACE	11.0		18.0
		AT ALTITUDE	62.0		63.9
		BALLISTIC RANGE WIND	-36.8		-43.5
		BALLISTIC CROSS WIND	-25.9		-25.6
	DENSITY	AT SURFACE	1.029		1.029
		BALLISTIC (SURFACE)	1.020		1.020
		BALLISTIC (AIR OBS.)	1.015		

NOTE: BOMBS RELEASED ON SAME RUN 1.57 SECONDS APART



RESULTS OF RANGE BOMBING NO. 152

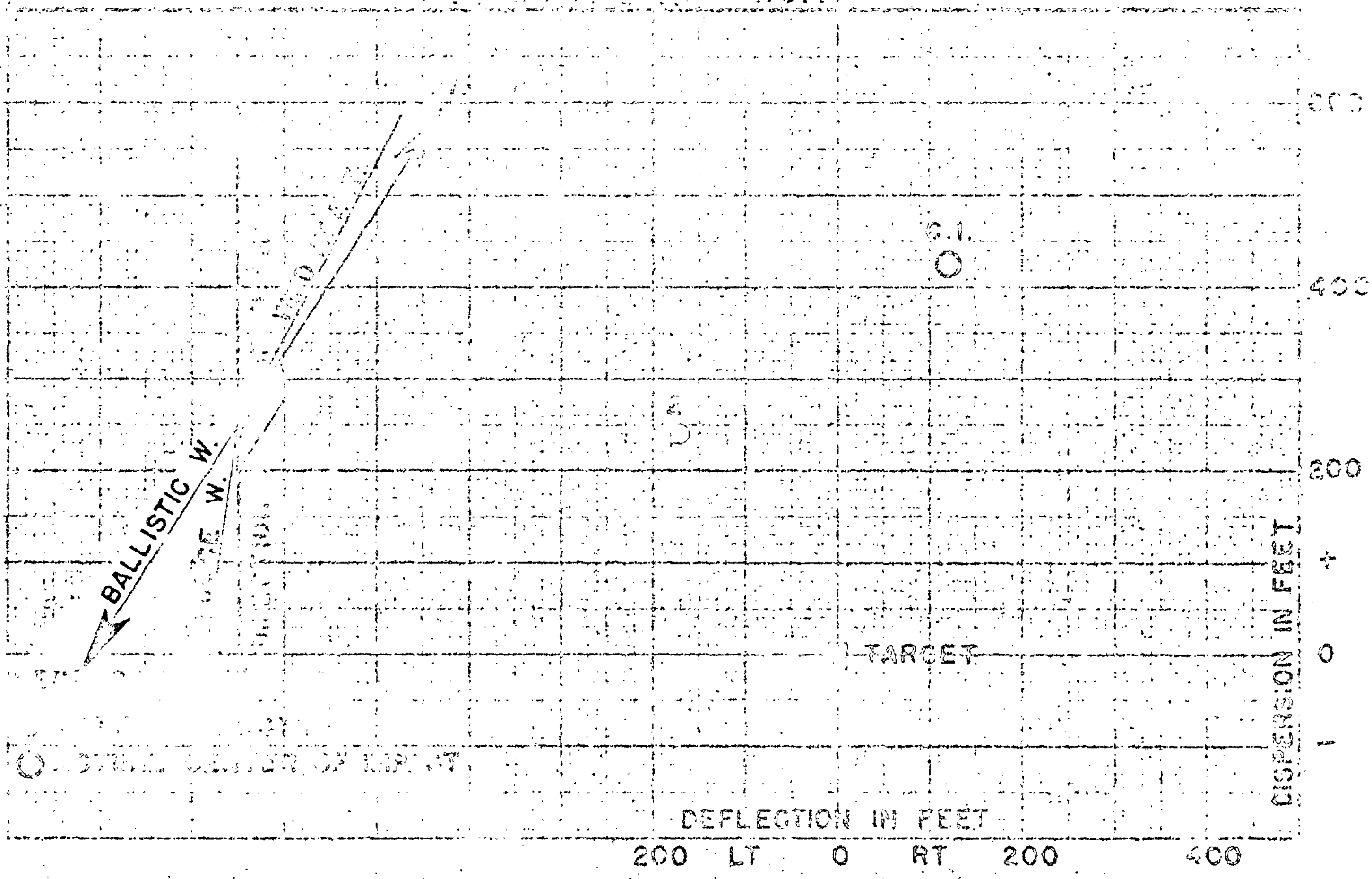
MAY 3, 1941 | 1000 LB A.P. BOMB T1 | AIRPLANE B-23

PILOT: LT. A. C. PERRY | BOMBARDIER: CAPT. M. F. SUMMERFELT

SKY: CLEAR | AIR: SMOOTH | TRAIL AND D.S. BASED ON BT-2000-B-1

BOMB NO.	TIME OF REL.	ALTITUDE AIR OBS FT.	ALTITUDE GR'ND OBS FT.	AIR SPEED CAL IND M/HR	AIR SPEED TRUE AIR OBS. M/HR	AIR SPEED TRUE GR'ND OBS. M/HR	GR'ND SPEED GR'ND OBS. M/HR	CLIMB OR GLIDE GR'ND OBS. [illegible]	HOR. RANGE FT.	DEVIATIONS FROM TARGET RANGE OVER FT.	RANGE SHORT FT.	DEFLECTION RIGHT FT.	DEFLECTION LEFT FT.
1	3:40	[illegible]	25161	120	178.5	170.0	114.6	+73.0	5418	609		411	
2	3:50	25155	24972	105	155.8	159.3	105.6	-126.7	5798	240			171
3													
4													
5													
6													
								CENTER OF IMPACT		425		120	
								MEAN DEVIATION		185		291	

			[illegible]	[illegible]	[illegible]
		[illegible]	3:33		3:59
	[illegible] VELOCITY [illegible]	[illegible]	0.0		0.0
		[illegible]	59.0		33.6
		[illegible]	-34.8		-35.3
		[illegible]	-22.1		-22.3
	[illegible]SITY	[illegible]	1.017		1.007
		[illegible]	1.016		1.008
		[illegible]	1.015		



RESULTS OF RANGE BOMBING NO. 157

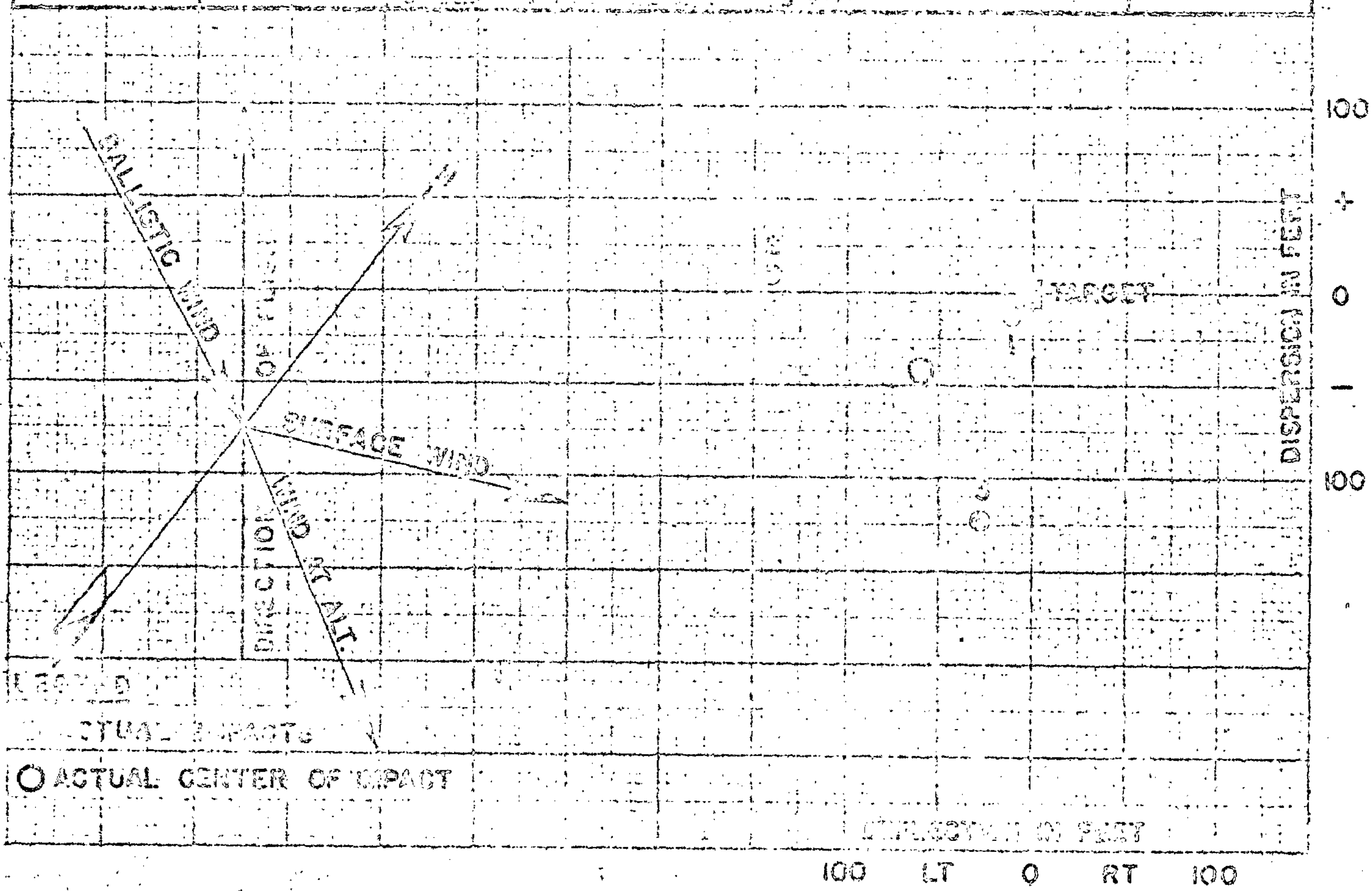
MAY 26, 1941 | 1000 LB. A.P. BOMB T1 | AIRPLANE B-23

PILOT: LT. A. C. PERRY | BOMBARDIER: CAPT. S. C. SMINK

SKY: HAZY | AIR: DISTURBED | TRAIL AND [illegible] BASED ON BT-2000-B-1

BOMB NO.	TIME OF REL.	ALTITUDE AIR OBS FT.	ALTITUDE GR'ND OBS FT.	AIR SPEED CAL IND M/HR	AIR SPEED TRUE AIR OBS. M/HR	AIR SPEED TRUE GR'ND OBS. M/HR	GR'ND SPEED GR'ND OBS. M/HR	CLIMB OR GLIDE GR'ND OBS. FT/[illegible]	HOR. RANGE FT.	DEVIATIONS FROM TARGET RANGE OVER FT.	RANGE SHORT FT.	DEFLECTION RIGHT FT.	DEFLECTION LEFT FT.
1	3:11	10500	10435	140	165.1	157.2	110.7	+25.3	3977		12		12
2	3:24	10510	10441	144	169.8	162.1	116.9	-32.2	4244	9			141
3	3:31	10510	10471	150	177.0	168.7	123.1	-26.3	4434		123		27
4													
5													
6													
									CENTER OF IMPACT		42		60
									MEAN DEVIATION	54		54	

		R.O.S.	H.O.S.	CAMERA
TIME		3:10		3:37
WIND VELOCITY M.P.H.	SURFACE	11.8		17.0
	AT ALTITUDE	48.5		52.6
	BALLISTIC RANGE [illegible]	-38.7		-39.4
	BALLISTIC CROSS [illegible]	20.9		21.7
DENSITY	AT SURFACE	.969		.973
	BALLISTIC SURFACE	.987		.989
	BALLISTIC [illegible]	.99[illegible]		



RESULTS OF RANGE BOMBING NO. 158

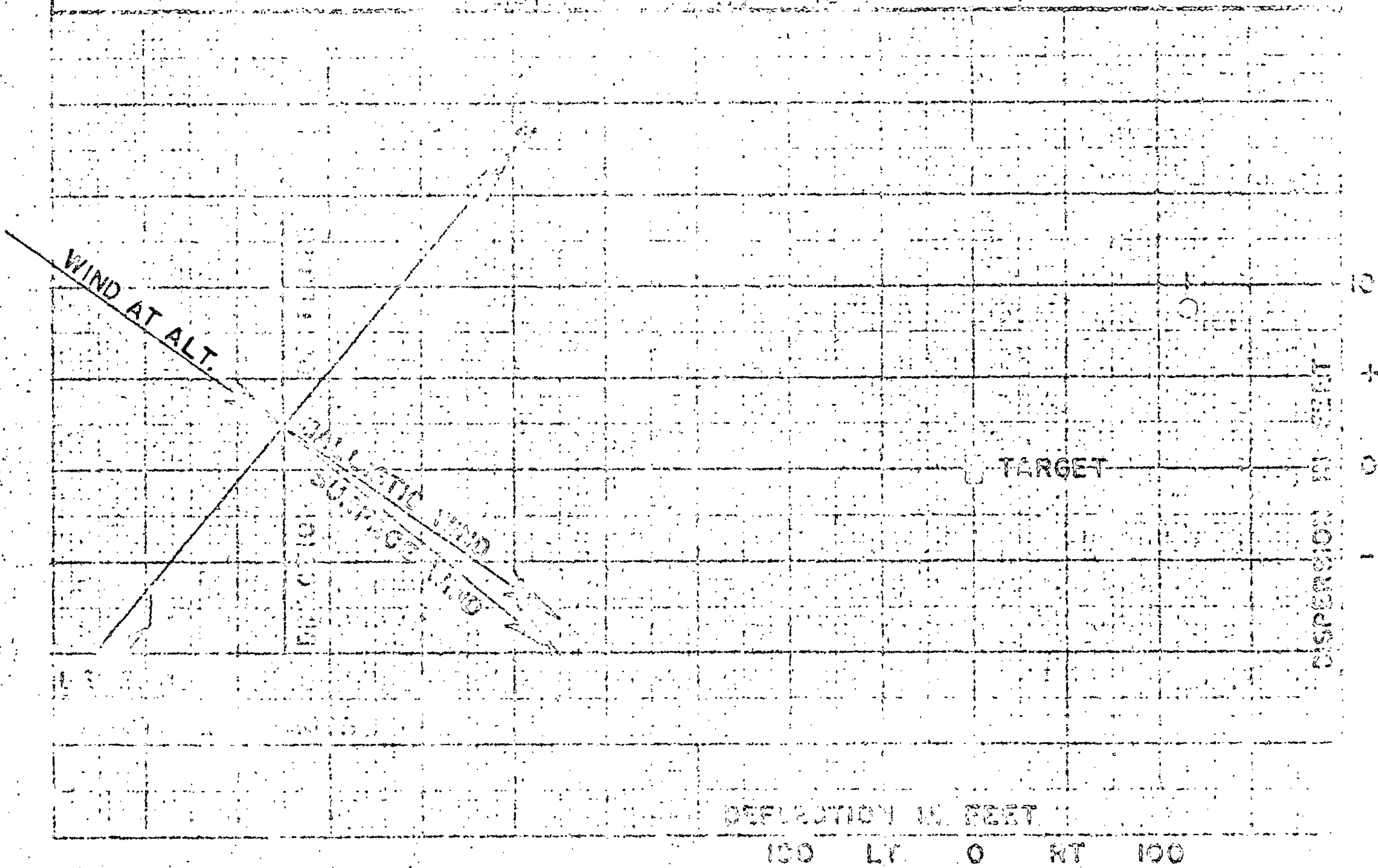
MAY 27, 19[illegible] | 1000 LB. A.P. BOMB T I | AIRPLANE B-13A

PILOT: LT. C.A. REISSAUS | BOMBARDIER: CAPT. M.F. SUMMERFELT

SKY: CLEAR | DIR: —— | TRAIL AND D.S. BASED ON BT-2000-B-1

BOMB NO.	TIME OF REL.	ALTITUDE AIR OBS FT.	ALTITUDE GR'ND OBS FT.	AIR SPEED CAL. IND M/HR	AIR SPEED TRUE AIR OBS. M/HR	AIR SPEED TRUE GR'ND OBS. M/HR	GR'ND SPEED GR'ND OBS. M/HR	CLIMB OR GLIDE GR'ND OBS. FT/MIN	HOR. RANGE FT.	RANGE OVER FT.	RANGE SHORT FT.	DEFLECTION RIGHT FT.	DEFLECTION LEFT FT.
1	9:3[illegible]	2220	2135	143	148.0	135.3	117.5	169.1	1927	87		117	
2													
3													
4													
5													
6													
CENTER OF IMPACT													
MEAN DEVIATION													

	D.S.	A.O.S.	CAMERA
[illegible]	9:50	10:30	9:52
[illegible]		19.0	12.0
[illegible]		27.4	21.1
[illegible]		-13.5	-13.0
[illegible]		21.9	17.7
[illegible]		.954	.965
DENSITY [illegible]		.960	.970
[illegible]	.979		



RESULTS OF RANGE BOMBING NO. 170

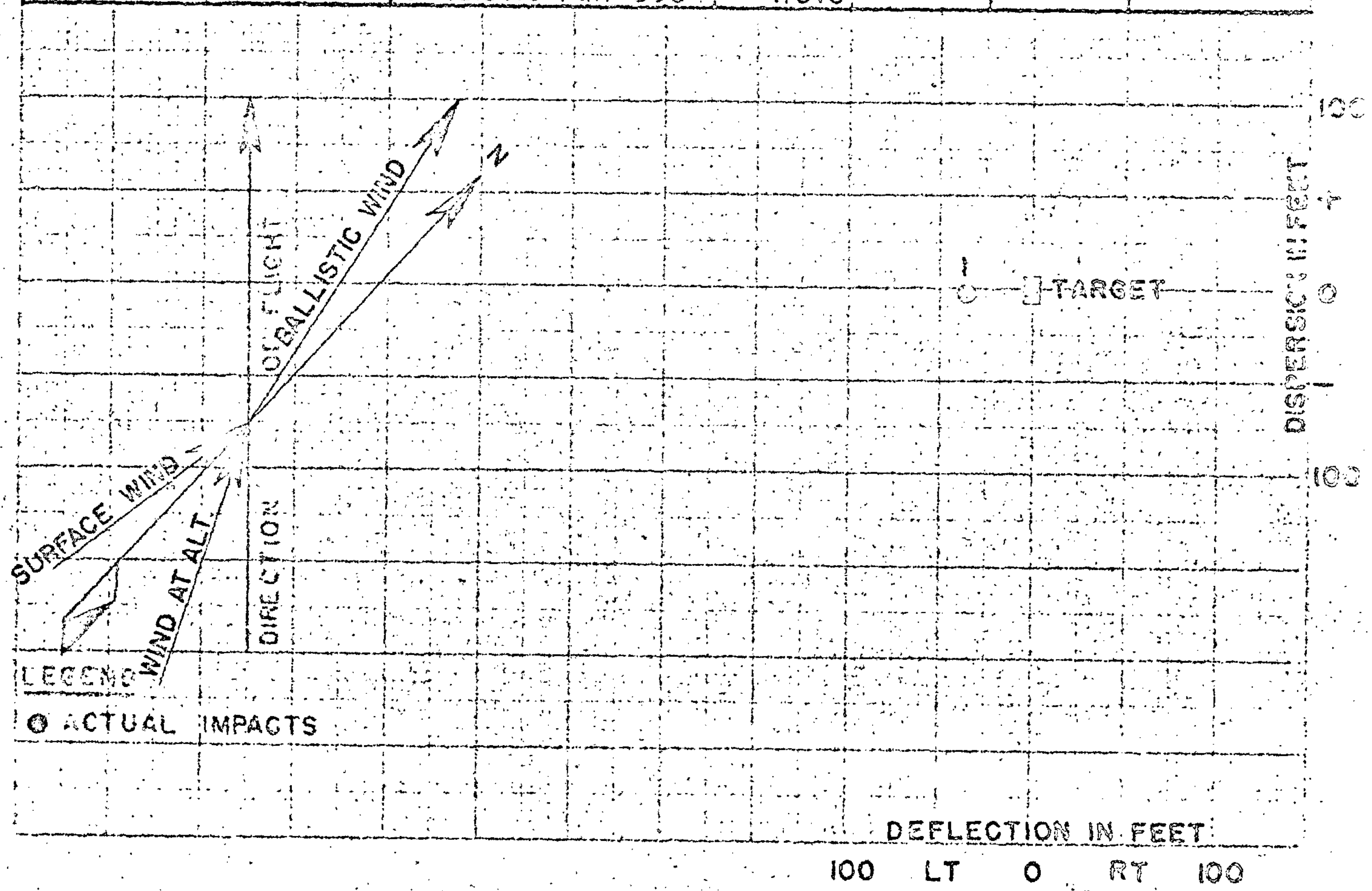
JUNE 3, 1941 — 1000 LB. A.P. BOMB T1 — AIRPLANE B-18A

PILOT: LT. R. BILLINGS — BOMBARDIER: CAPT. S.C. SMINK

SKY: CLOUDS — AIR: DISTURBED — TRAIL AND D.S. BASED ON BT-2000-B-1

BOMB NO.	TIME OF REL.	ALTITUDE AIR OBS FT.	ALTITUDE GR'ND OBS FT.	AIR SPEED CAL IND M/HR	AIR SPEED TRUE AIR OBS. M/HR	AIR SPEED TRUE GR'ND OBS. M/HR	GR'ND SPEED GR'ND OBS. M/HR	CLIMB OR GLIDE GR'ND OBS. FT/MIN	HOR. RANGE FT.	DEVIATIONS FROM TARGET RANGE OVER FT.	RANGE SHORT FT.	DEFLECTION RIGHT FT.	DEFLECTION LEFT FT.
1	11:16	2110	2079	148	152.9	157.4	164.7	-5.2	2753		3		36
2													
3													
4													
5													
6													
CENTER OF IMPACT													
MEAN DEVIATION													

		R.O.S.	R.O.S.	CAMERA
TIME		10:51	11:18	11:20
WIND VELOCITY M.P.H.	SURFACE	2.0	2.0	4.0
	AT ALTITUDE	11.2	7.9	7.1
	BALLISTIC RANGE WIND	5.6		6.4
	BALLISTIC CROSS WIND	3.6		0.0
DENSITY	AT SURFACE	.994	.994	.988
	BALLISTIC (SURFACE)	.997	.997	.991
	BALLISTIC (AIR OBS.)	1.010		



RESULTS OF RANGE BOMBING NO. 171

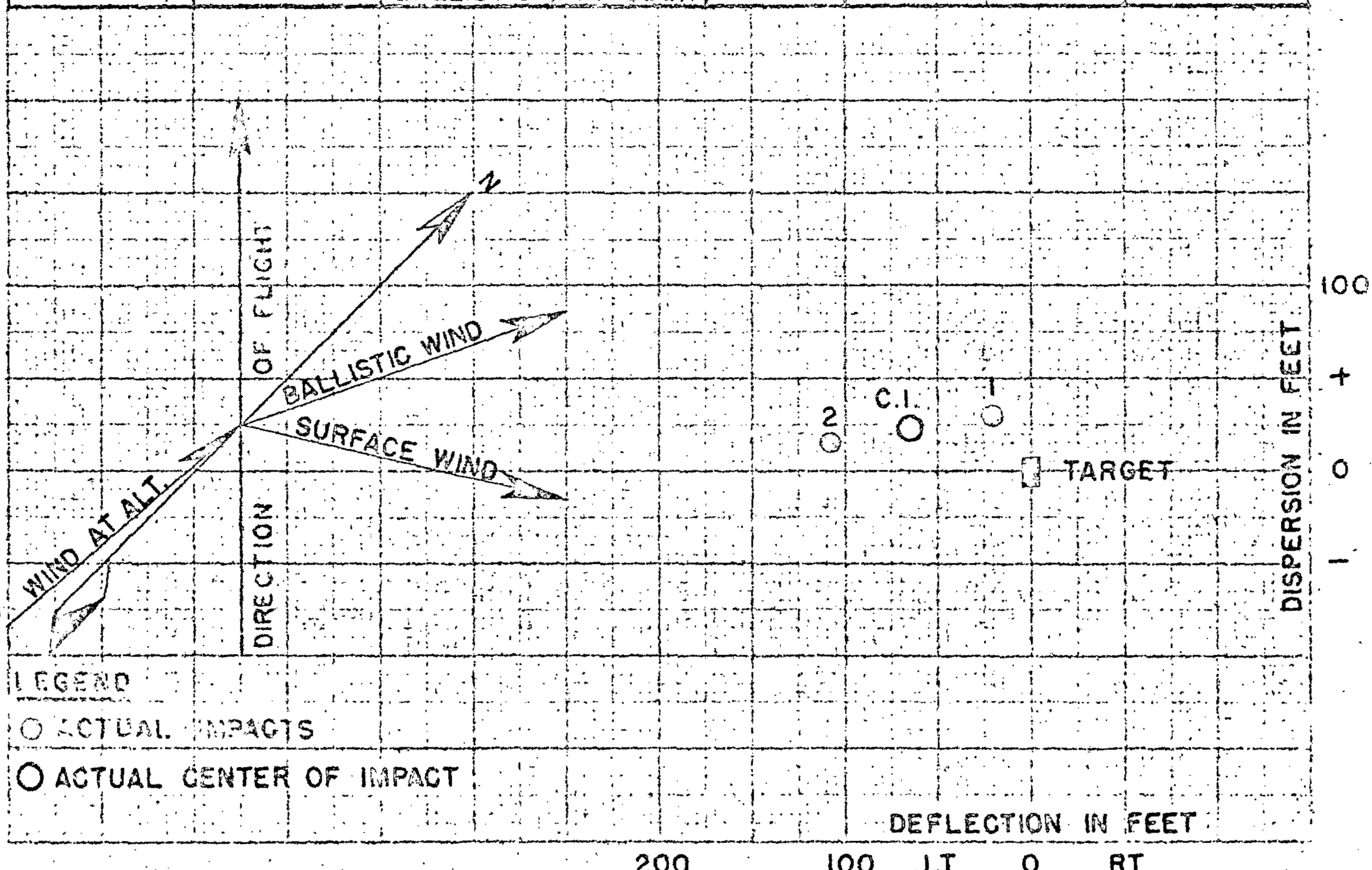
JUNE 3, 1941 — 1000 LB A.P. BOMB T.I — AIRPLANE B-18A

PILOT: LT. A.C. PERRY — BOMBARDIER: CAPT. M.F. SUMMERFELT

SKY: ——— AIR: SMOOTH — TRAIL AND D.S. BASED ON BT-2000-B-1

BOMB NO.	TIME OF REL.	ALTITUDE AIR OBS FT.	ALTITUDE GR'ND OBS FT.	AIR SPEED CAL IND M/HR	AIR SPEED TRUE AIR OBS. M/HR	AIR SPEED TRUE GR'ND OBS. M/HR	GR'ND SPEED GR'ND OBS. M/HR	CLIMB OR GLIDE GR'ND OBS. FT/MIN	HOR. RANGE FT.	RANGE OVER FT.	RANGE SHORT FT.	DEFLECTION RIGHT FT.	DEFLECTION LEFT FT.
1	2:31	2040	2051	152	157.0	161.4	164.2	-82.1	2715	30			21
2	2:40	2080	2077	152	157.1	163.2	166.5	-47.2	2765	15			108
3													
4													
5													
6													
CENTER OF IMPACT										23			65
MEAN DEVIATION										8		44	

		R.O.S.	R.O.S.	CAMERA
TIME		2:28	3:07	2:44
WIND VELOCITY M.P.H.	SURFACE	5.0	6.0	6.0
	AT ALTITUDE	4.0	5.2	10.4
	BALLISTIC RANGE WIND	1.4		6.1
	BALLISTIC CROSS WIND	3.9		4.5
DENSITY	AT SURFACE	.991	.991	.934
	BALLISTIC (SURFACE)	.994	.994	.988
	BALLISTIC (AIR OBS.)	1.008		



LEGEND

○ ACTUAL IMPACTS

◯ ACTUAL CENTER OF IMPACT

RESULTS OF RANGE BOMBING NO. 173

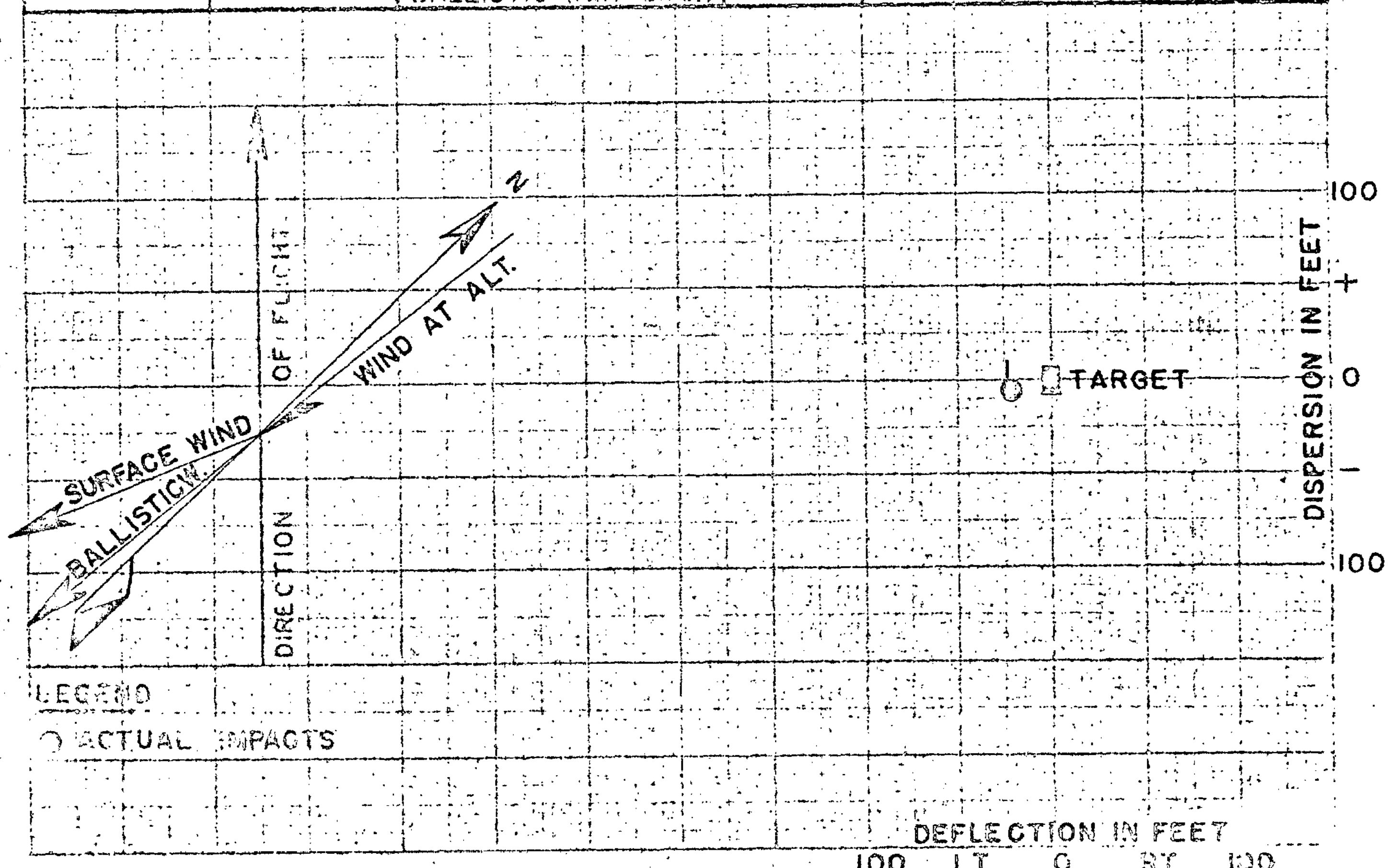
JUNE 6, 1941 — 1000 LB. A.P. BOMB T1 — AIRPLANE B-18 A

PILOT : LT. A. C. PERRY — BOMBARDIER : CAPT. S. C. SMINK

SKY : VERY HAZY — AIR : SMOOTH — TRAIL AND D.S. BASED ON BT-2000-B-1

BOMB NO.	TIME OF REL.	ALTITUDE AIR OBS FT.	ALTITUDE GR'ND OBS FT.	AIR SPEED CAL IND M/HR	AIR SPEED TRUE AIR OBS. M/HR	AIR SPEED TRUE GR'ND OBS. M/HR	GR'ND SPEED GR'ND OBS. M/HR	CLIMB OR GLIDE GR'ND OBS. FT/MIN	HOR. RANGE FT.	DEVIATIONS FROM TARGET RANGE OVER FT.	RANGE SHORT FT.	DEFLECTION RIGHT FT.	DEFLECTION LEFT FT.
1	10:19	2130	2122	145	149.9	157.9	151.3	+103.4	2515		6		21
2													
3													
4													
5													
6													
CENTER OF IMPACT													
MEAN DEVIATION													

		R.O.S.	R.O.S.	CAMERA
TIME		10:15	11:10	10:28
WIND VELOCITY M.P.H.	SURFACE	2.0	5.0	0.0
	AT ALTITUDE	10.8	5.3	6.1
	BALLISTIC RANGE WIND	-5.0		-1.7
	BALLISTIC CROSS WIND	-6.2		-4.4
DENSITY	AT SURFACE	.991	.989	.992
	BALLISTIC (SURFACE)	.994	.992	.995
	BALLISTIC (AIR OBS.)	1.001		



Appendix C

Individual Standard Elements and Ballistic Coefficients from Reduction of Field Data

Appendix C

Program Group Serial Number	Date of Release Run No.	Y Standard Altitude ft.	U Standard True Air Speed mi./hr.	X Standard Range ft.	T Standard Time of Flight sec.	λ Standard Trail ft.	C_X	C_T	C_λ
-11	4/28/41-1	25000	200	11185	40.92	818	4.27	4.26	4.26
					WE 41.25	915		3.39	3.77
-12	2			11372	41.32	748	8.53	3.24	4.68
-15	4/29/41-1	10000	160	5753			5.46		
-14	2			5775			7.00		
					WE 25.12	119		9.94	8.00
-13	3			5776	25.14	124	7.14	8.61	7.70
-16	5/3/41--1	25000	200	11280	39.72	372	5.74	24.25	9.95
-17	2			11289			5.92		
					WE 41.85	987		2.44	3.65
-18	1			11367	41.50	808	8.32	2.91	4.41
-19	2			11195	40.89	799	4.38	4.36	4.46
					WE 40.93	812		4.22	4.39
-20	5/26/41-1	10000	160	5691	25.20	223	3.34	6.71	4.27
-21	2			5743	25.24	179	4.96	5.90	5.06
					WE 25.05	135		16.30	7.08
-22	3			5705	25.34	242	3.68	4.30	3.94
-23	5/27/41-1	2000	160	2510[1]	10.80[1]				
					WE 10.89[1]				
-24	6/3/41--1	2000	160	2623	11.18	1	-19.60	8.89	135.39
					WE 11.22	10		4.10	17.60

[1] Not included in group mean for reasons given on page 8 of text.

Appendix C (Cont'd)

Program Group Serial Number	Date of Release Run No.	Y Standard Altitude ft.	U Standard True Air Speed mi./hr.	X Standard Range ft.	T Standard Time of Flight sec.	λ Standard Trail ft.	C_X	C_T	C_λ
-25	6/3/41--1	2000	160	2623	11.18	1	-21.14	10.44	220.02
-26	2			2613	WE 11.34	38	24.33	1.48	4.61
-27	6/6/41--1	2000	160	2572	11.16	46	2.42	91.02	3.79

Appendix D

Mean Standard Elements of Altitude Groups and Relations Between the Ballistic Coefficients and the Altitude of Release

Appendix D
Table 1
Range

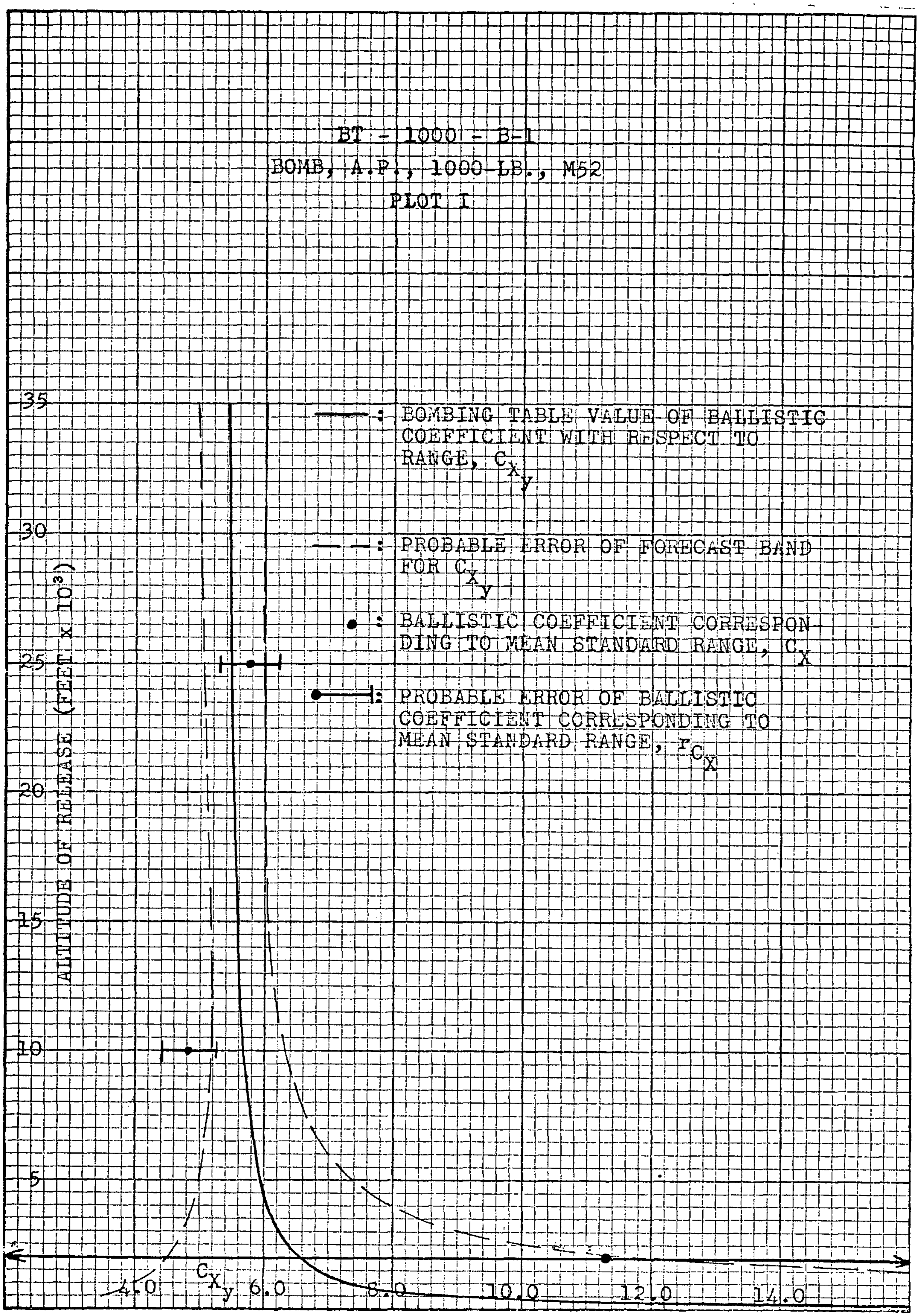
Y Standard Altitude ft.	U Standard True Air Speed mi./hr.	V Calibrated Indicated Air Speed Corresponding to Standard True Air Speed mi./hr.	N Number of Bombs	P Weight of Groups	X Mean Standard Range ft.	r_X Probable Error of Mean Standard Range ft.	C_X Ballistic Coefficient Corresponding to Mean Standard Range	r_{C_X} Probable Error of Ballistic Coefficient Corresponding to Mean Standard Range	C_{X_y} Value of Ballistic Coefficient from C:Y Relation	$X-X_f$ Mean Standard Range Minus Range Corresponding to C_{X_y} ft.
35000									5.43	
30000									5.45	
25000	200	134.8	6	1.00	11281	22.2	5.76	0.460	5.48	14
20000									5.52	
15000									5.58	
10000	160	136.6	6	1.33	5740	9.8	4.85	0.428	5.69	-16
5000									5.95	
2000	160	155.0	4	0.67	2608	8.2	11.32	9.455	6.53	7

Appendix D
Table 2
Time of Flight

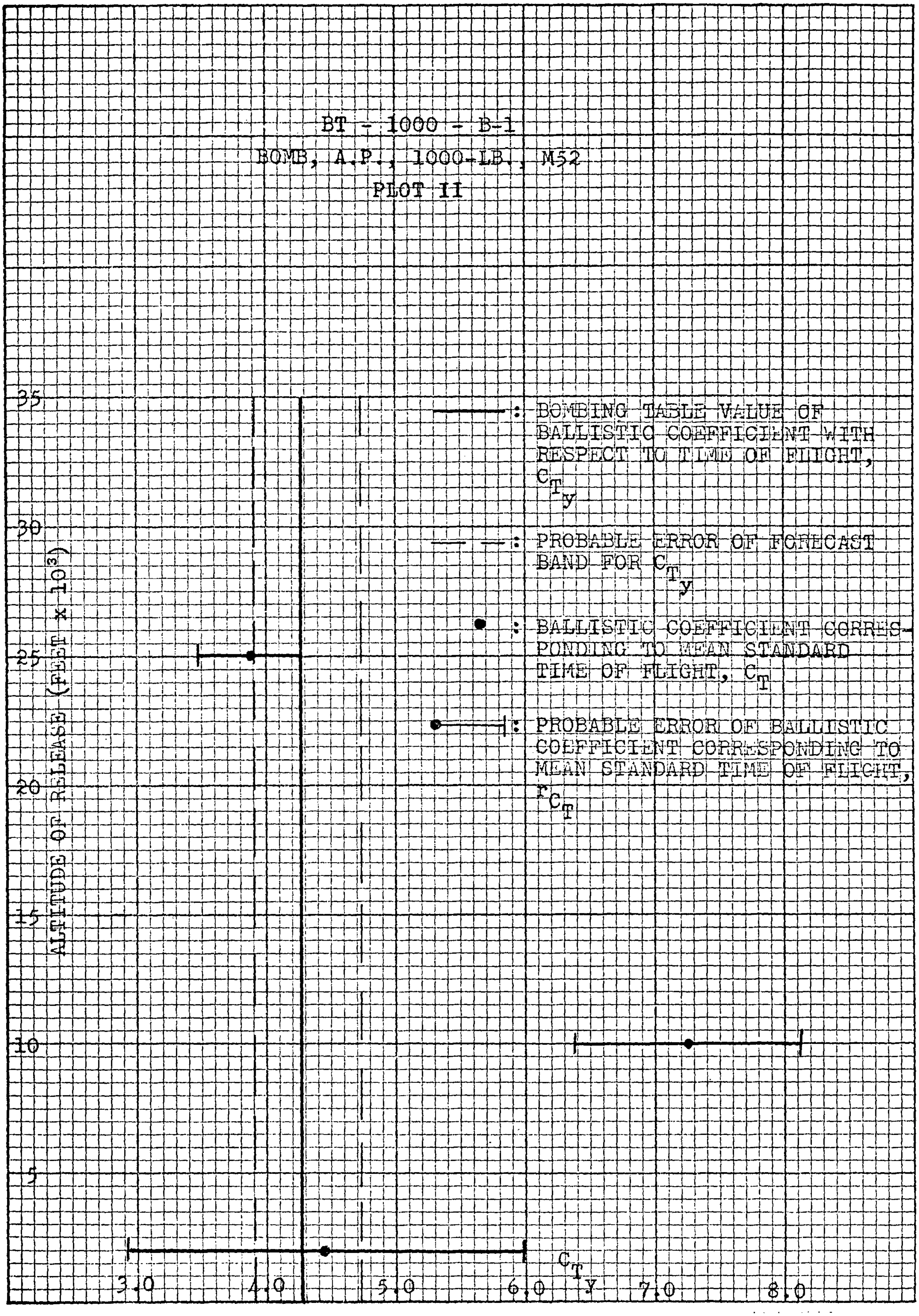
Y Standard Altitude ft.	U Standard True Air Speed mi./hr.	V Calibrated Indicated Air Speed Corresponding to Standard True Air Speed mi./hr.	N Number of Bombs	P Weight of Groups	T Mean Standard Time of Flight sec.	r_T Probable Error of Mean Standard Time of Flight sec.	C_T Ballistic Coefficient Corresponding to Mean Standard Time of Flight	r_{C_T} Probable Error of Ballistic Coefficient Corresponding to Mean Standard Time of Flight	C_{T_y} Value of Ballistic Coefficient from C:Y Relation	$T-T_f$ Mean Standard Time of Flight Minus Time of Flight Corresponding to C_{T_y} sec.
35000									4.28	
30000									4.28	
25000	200	134.8	6	1.00	41.05	0.150	3.87	0.409	4.28	0.14
20000									4.28	
15000									4.28	
10000	160	136.6	5	1.33	25.18	0.028	7.25	0.861	4.28	-0.17
5000									4.28	
2000	160	155.0	3	0.67	11.22	0.022	4.45	1.532	4.28	0.04

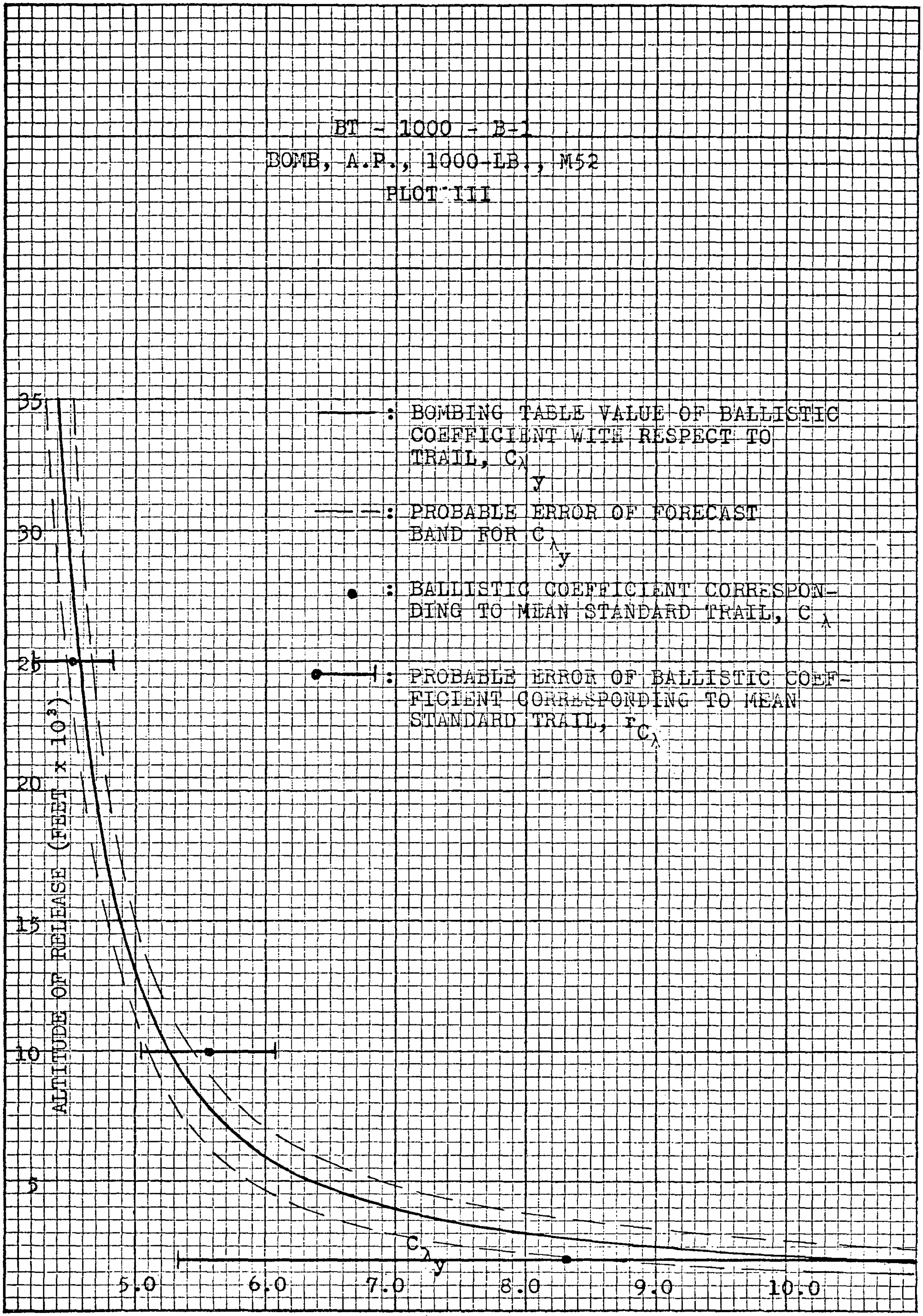
Appendix D
Table 3
Trail

Y Standard Altitude ft.	U Standard True Air Speed mi./hr.	V Calibrated Indicated Air Speed Corresponding to Standard True Air Speed mi./hr	N Number of Bombs	P Weight of Groups	λ Mean Standard Trail ft.	r_λ Probable Error of Mean Standard Trail ft.	C_λ Ballistic Coefficient Corresponding to Mean Standard Trail	r_{C_λ} Probable Error of Ballistic Coefficient Corresponding to Mean Standard Trail	C_{λ_y} Value of Ballistic Coefficient from C:Y Relation	$\lambda - \lambda_f$ Mean Standard Trail Minus Trail Corresponding to C_{λ_y} ft.
35000									4.41	
30000									4.48	
25000	200	134.8	6	1.00	775	49.0	4.52	0.308	4.57	7
20000									4.69	
15000									4.89	
10000	160	136.6	5	1.33	172	15.9	5.56	0.517	5.26	-10
5000									6.34	
2000	160	155.0	3	0.67	21	7.7	8.31	2.974	10.73	5

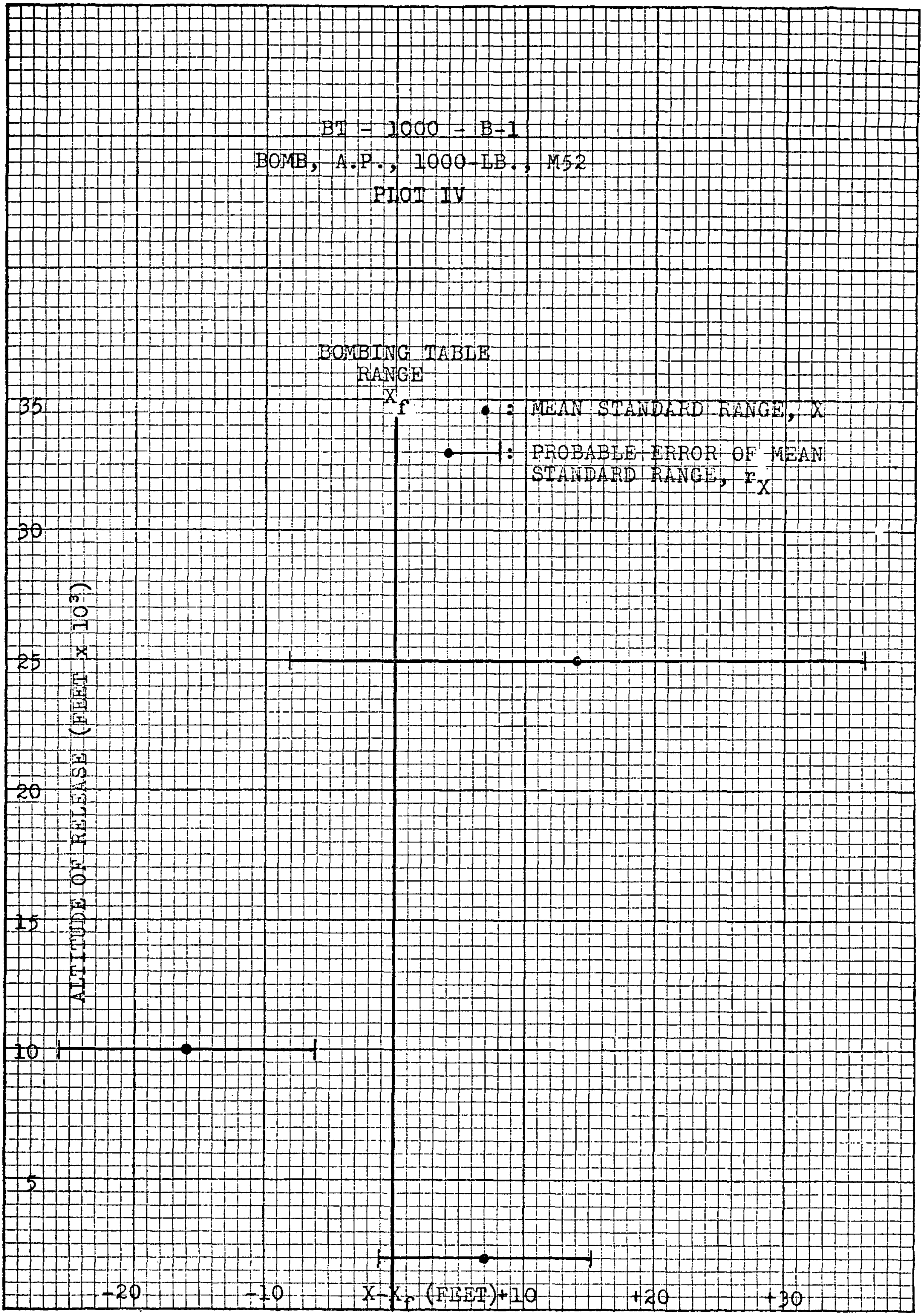


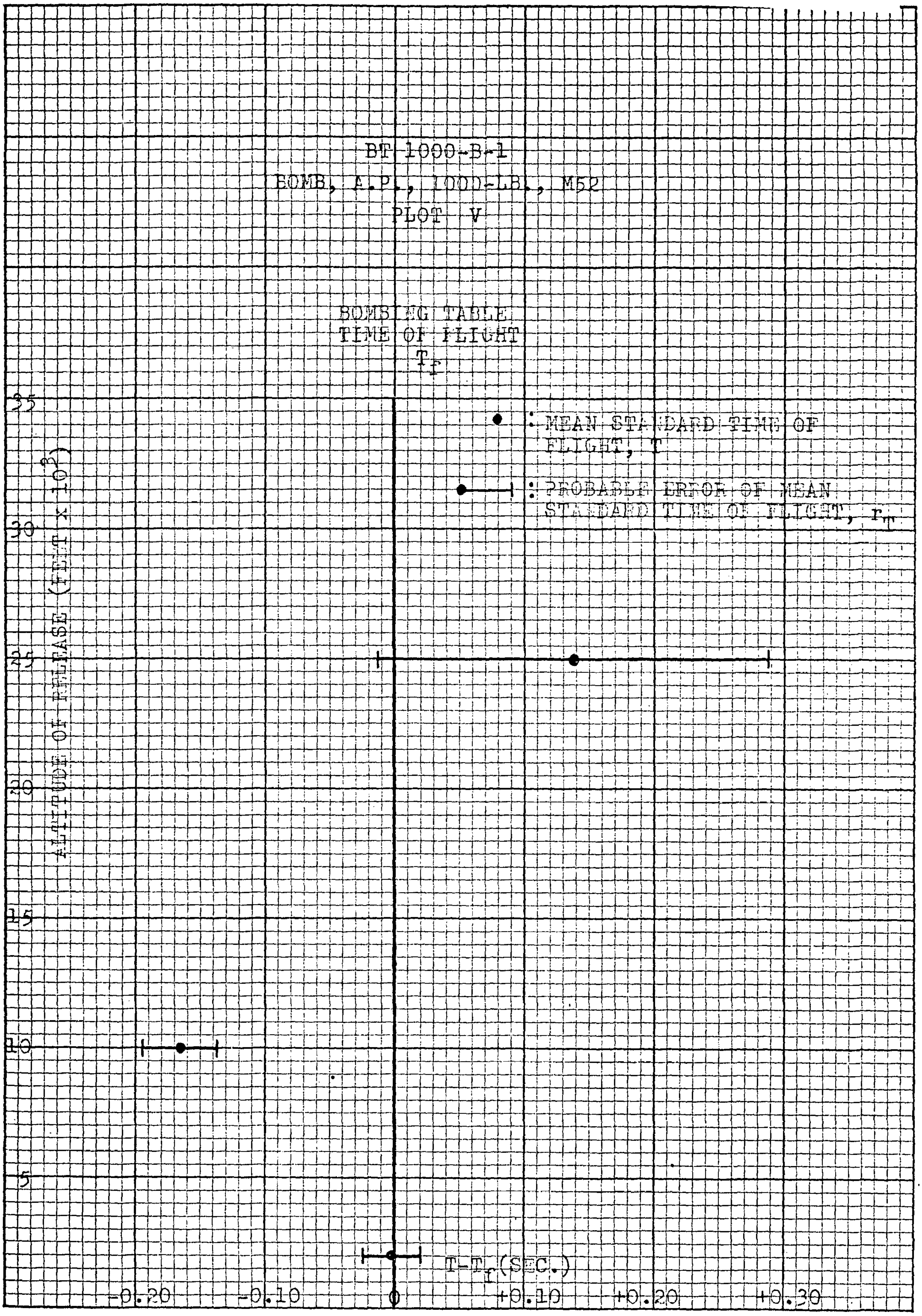
BT - 1000 - B-1
BOMB, A.P., 1000-LB., M52
PLOT I
ALTITUDE OF RELEASE (FEET x 10³)
35
30
25
20
15
10
5
: BOMBING TABLE VALUE OF BALLISTIC COEFFICIENT WITH RESPECT TO RANGE, C_{x_y}
: PROBABLE ERROR OF FORECAST BAND FOR C_{x_y}
: BALLISTIC COEFFICIENT CORRESPONDING TO MEAN STANDARD RANGE, C_x
: PROBABLE ERROR OF BALLISTIC COEFFICIENT CORRESPONDING TO MEAN STANDARD RANGE, r_{C_x}
4.0
C_{x_y}
6.0
8.0
10.0
12.0
14.0

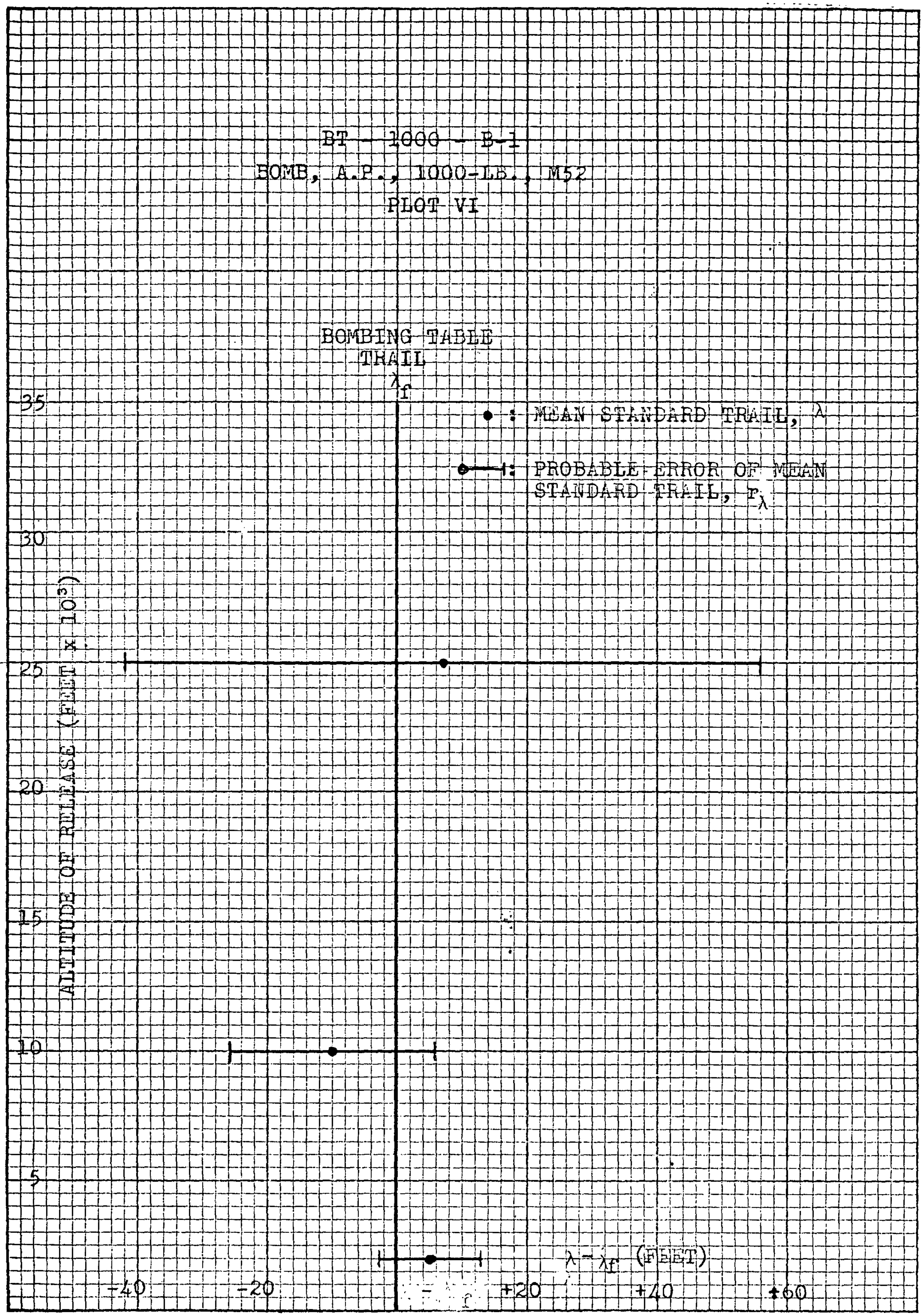

BT - 1000 - B-1
BOMB, A.P., 1000-LB., M52
PLOT II
: BOMBING TABLE VALUE OF BALLISTIC COEFFICIENT WITH RESPECT TO TIME OF FLIGHT, C_{T_y}
: PROBABLE ERROR OF FORECAST BAND FOR C_{T_y}
: BALLISTIC COEFFICIENT CORRESPONDING TO MEAN STANDARD TIME OF FLIGHT, C_T
: PROBABLE ERROR OF BALLISTIC COEFFICIENT CORRESPONDING TO MEAN STANDARD TIME OF FLIGHT, r_{C_T}
ALTITUDE OF RELEASE (FEET x 10^3)
35
30
25
20
15
10
5
C_{T_y}
3.0
4.0
5.0
6.0
7.0
8.0



BT - 1000 - B-1
BOMB, A.P., 1000-LB., M52
PLOT III
: BOMBING TABLE VALUE OF BALLISTIC COEFFICIENT WITH RESPECT TO TRAIL, C_{λ_y}
: PROBABLE ERROR OF FORECAST BAND FOR C_{λ_y}
: BALLISTIC COEFFICIENT CORRESPONDING TO MEAN STANDARD TRAIL, C_λ
: PROBABLE ERROR OF BALLISTIC COEFFICIENT CORRESPONDING TO MEAN STANDARD TRAIL, r_{C_λ}
ALTITUDE OF RELEASE (FEET x 10^3)
35
30
25
20
15
10
5
C_{λ_y}
5.0
6.0
7.0
8.0
9.0
10.0


BT - 1000 - B-1
BOMB, A.P., 1000-LB., M52
PLOT IV
BOMBING TABLE RANGE
X_f
• : MEAN STANDARD RANGE, X
: PROBABLE ERROR OF MEAN STANDARD RANGE, r_X
ALTITUDE OF RELEASE (FEET x 10^3)
35
30
25
20
15
10
5
-20
-10
X-X_f (FEET)
+10
+20
+30


BT-1000-B-1
BOMB, A.P., 1000-LB., M52
PLOT V
BOMBING TABLE
TIME OF FLIGHT
T_f
: MEAN STANDARD TIME OF FLIGHT, T
: PROBABLE ERROR OF MEAN STANDARD TIME OF FLIGHT, r_T
ALTITUDE OF RELEASE (FEET x 10^3)
35
30
25
20
15
10
5
$T-T_f$ (SEC.)
-0.20
-0.10
0
+0.10
+0.20
+0.30


BT - 1000 - B-1
BOMB, A.P., 1000-LB., M52
PLOT VI
BOMBING TABLE
TRAIL
λ_f
• : MEAN STANDARD TRAIL, λ
PROBABLE ERROR OF MEAN STANDARD TRAIL, r_λ
ALTITUDE OF RELEASE (FEET x 10^3)
35
30
25
20
15
10
5
$\lambda - \lambda_f$ (FEET)
-40
-20
+20
+40
+60